US008534094B2

(12) **United States Patent**
Teo

(10) **Patent No.: US 8,534,094 B2**
(45) **Date of Patent: Sep. 17, 2013**

(54) **METHOD AND APPARATUS FOR LIQUEFYING A HYDROCARBON STREAM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1166 days.

(21) Appl. No.: **12/100,287**

(22) Filed: **Apr. 9, 2008**

(65) **Prior Publication Data**

US 2009/0255294 A1 Oct. 15, 2009

(51) **Int. Cl.**
F25J 3/00 (2006.01)

(52) **U.S. Cl.**
USPC **62/620**

(58) **Field of Classification Search**
USPC 62/620, 618, 606, 621, 613, 619
See application file for complete search history.

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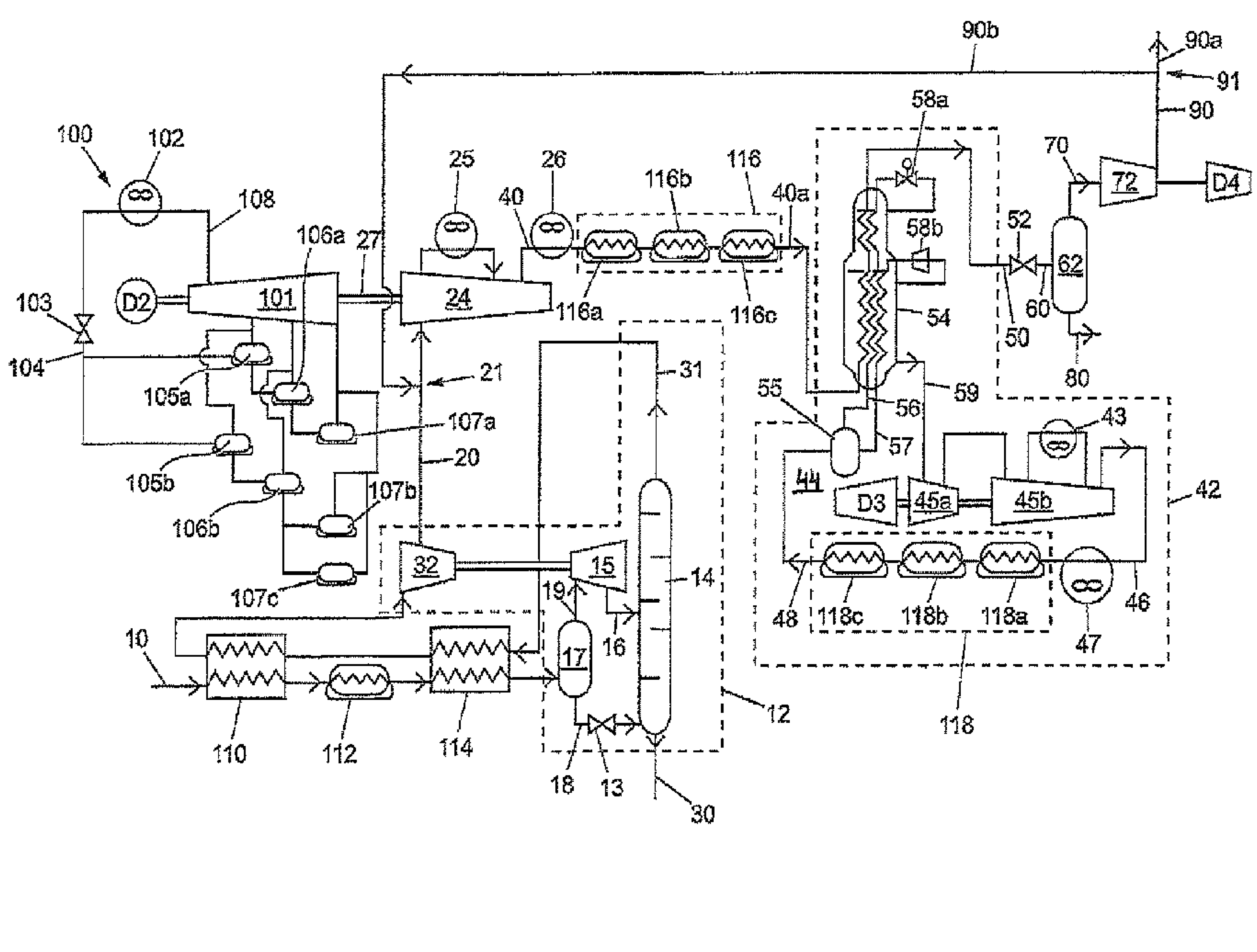
(57) **ABSTRACT**

Method and apparatus for liquefying a hydrocarbon stream. A hydrocarbon feed stream is passed through an NGL recovery system to separate the hydrocarbon feed stream into at least a methane-enriched overhead stream and a C_2+ enriched bottom stream. The methane-enriched overhead stream is then passed through a first compressor to provide a methane-compressed stream, which is liquefied to provide a first liquefied stream. The pressure of the first liquefied stream is reduced to provide a mixed phase stream, which is passed through an end gas/liquid separator to provide an end gaseous stream and a liquefied hydrocarbon product stream. The end gaseous stream is passed through one or more end-compressors to provide an end compressed stream, of which at least a recycle fraction is fed into the methane-enriched overhead stream. The temperature of the first liquefied stream may be controlled to change the amount of the end gaseous stream.

20 Claims, 3 Drawing Sheets



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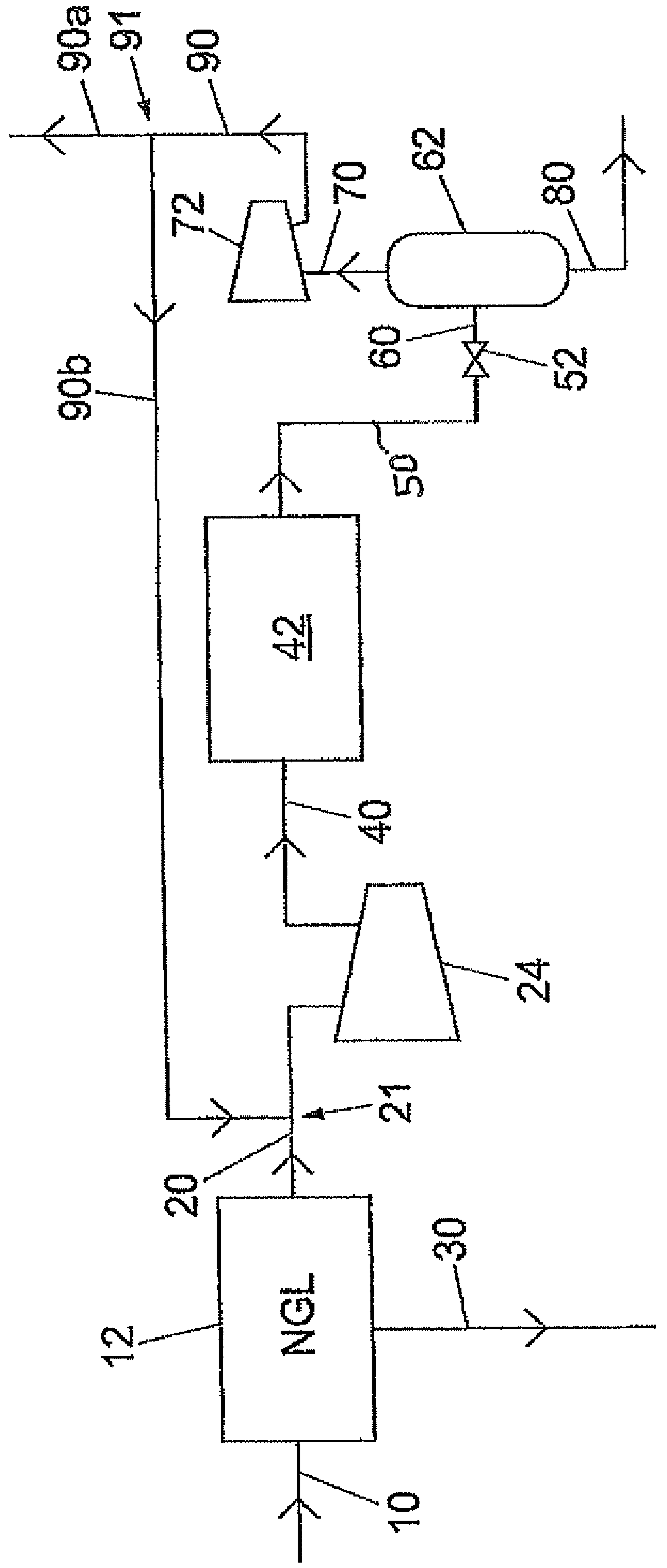
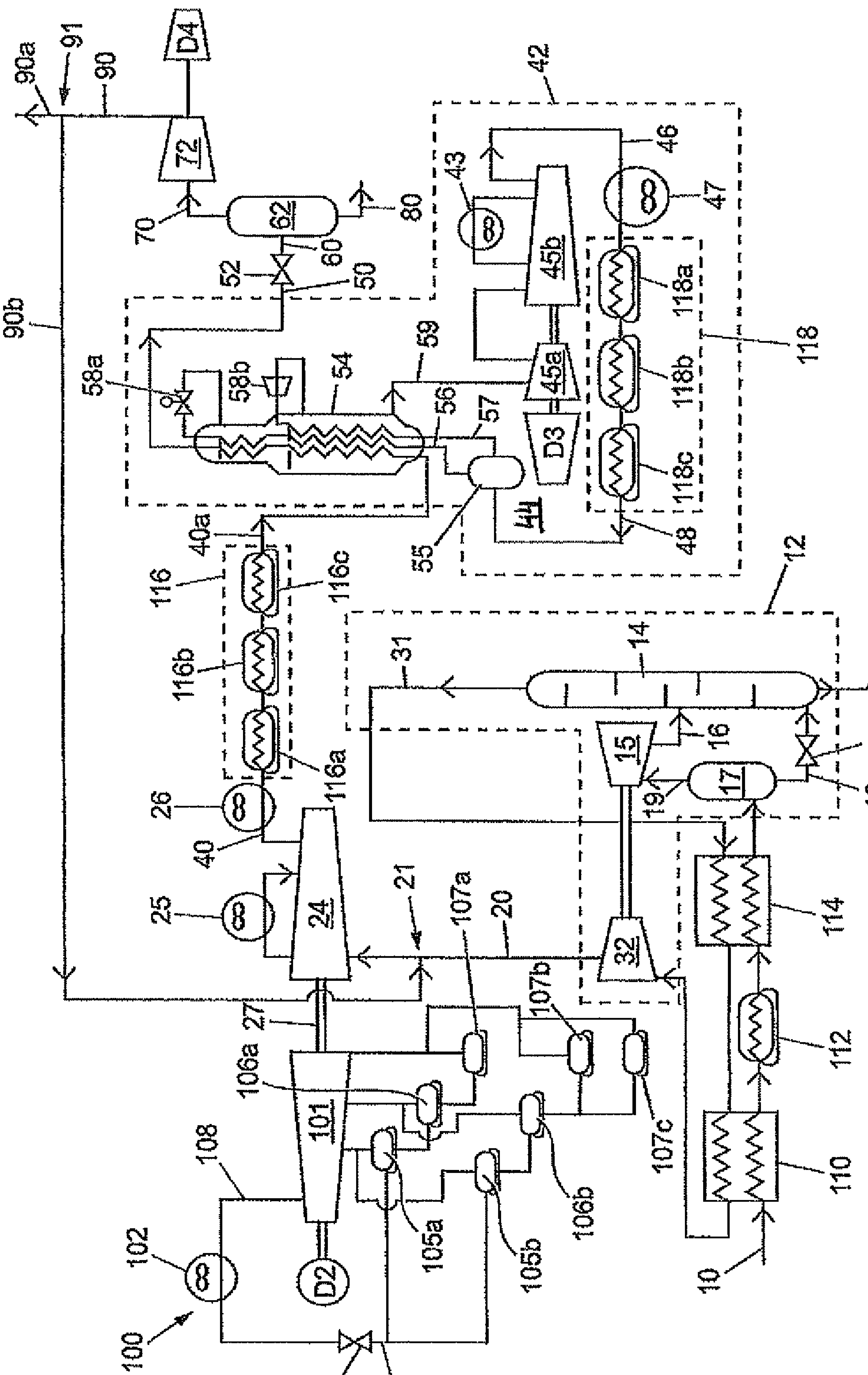


Fig. 1


D4
90a
91
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70
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42
43
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45b
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55
56
57
58a
58b
54
59
118a
118b
118c
118
48
90b
40a
116
116c
116b
116a
26
40
25
24
21
20
107a
107b
107c
27
106a
101
105a
105b
106b
108
102
D2
100
103
104
12
14
31
30
16
15
13
17
19
18
32
114
112
110
10

Fig. 2

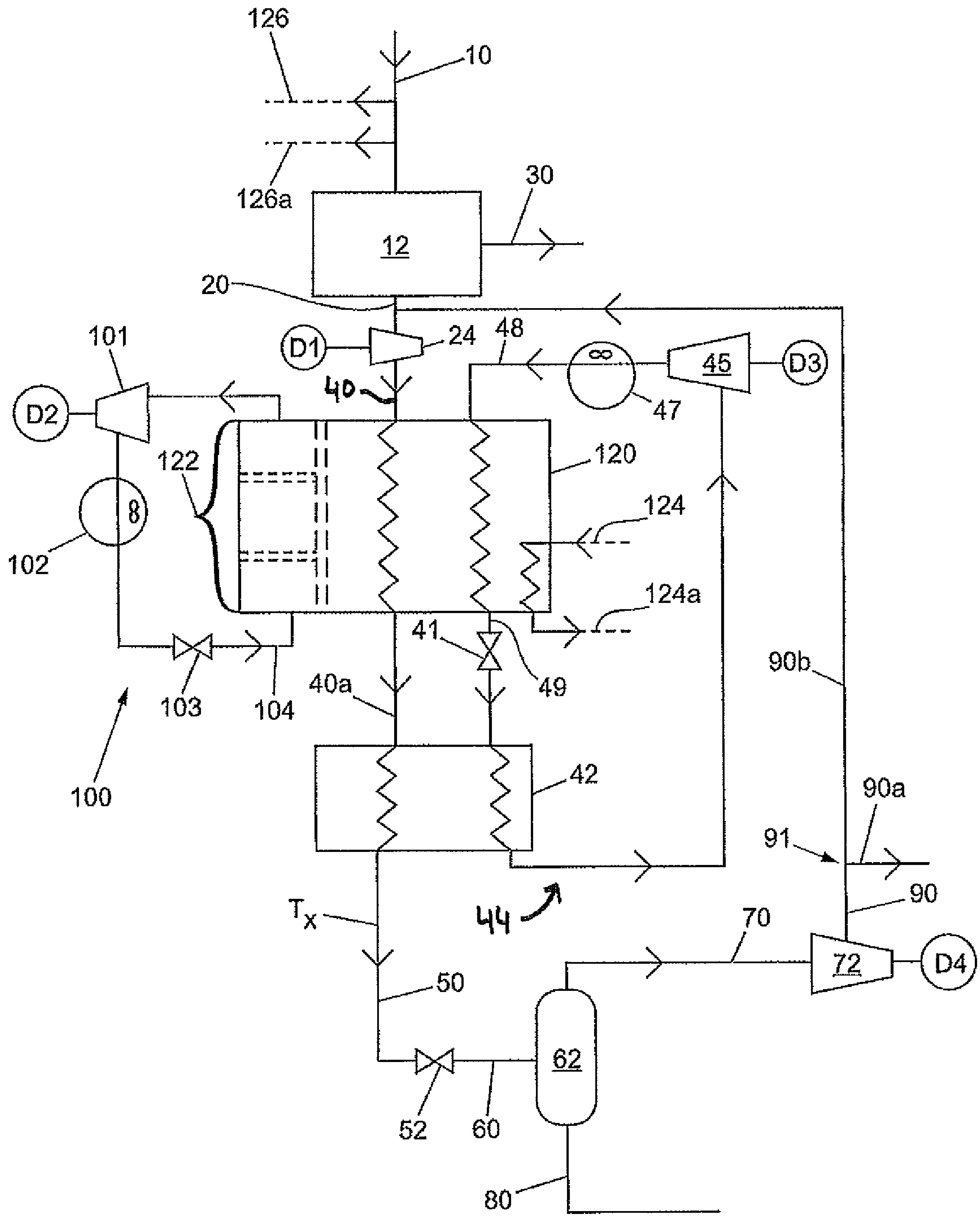
126
10
126a
30
12
20
101
D1
24
48
45
D3
D2
40
47
122
120
124
102
8
124a
41
103
104
49
90b
40a
42
100
90a
91
Tx
44
90
70
72
D4
50
62
52
60
80

Fig. 3

METHOD AND APPARATUS FOR LIQUEFYING A HYDROCARBON STREAM

The present invention relates to a method and apparatus for liquefying a hydrocarbon stream, for instance a natural gas stream.

Natural gas is a useful fuel source, as well as being a source of various hydrocarbon compounds. It is often desirable to liquefy natural gas in a liquefied natural gas (LNG) plant at or near the source of a natural gas stream for a number of reasons. As an example, natural gas can be stored and transported over long distances more readily as a liquid than in gaseous form because it occupies a small volume and does not need to be stored at high pressure.

Usually, natural gas, comprising predominantly methane, enters an LNG plant at elevated pressures and is pre-treated to produce a purified feed stream suitable for liquefaction at cryogenic temperatures. The purified gas is processed through a plurality of cooling stages using heat exchangers to progressively reduce its temperature until liquefaction is achieved. The liquid natural gas is then further cooled and expanded to final atmospheric pressure suitable for storage and transportation.

In addition to methane, natural gas usually includes some heavier hydrocarbons and impurities, including but not limited to carbon dioxide, sulphur, hydrogen sulphide and other sulphur compounds, nitrogen, helium, water, other non-hydrocarbon acid gases, ethane, propane, butanes, C_5+ hydrocarbons and aromatic hydrocarbons. These and any other common or known heavier hydrocarbons and impurities either prevent or hinder the usual known methods of liquefying the methane, especially the most efficient methods of liquefying methane. Most known or proposed methods of liquefying hydrocarbons, especially liquefying natural gas, are based on reducing as far as possible the levels of at least most of the heavier hydrocarbons and impurities prior to the liquefying process.

Hydrocarbons heavier than methane and usually ethane are typically condensed and recovered as natural gas liquids (NGLs) from a natural gas stream. The methane is usually separated from the NGLs in a high pressure scrub column, and the NGLs are then subsequently fractionated in a number of dedicated distillation columns to yield valuable hydrocarbon products, either as product steams per se or for use in liquefaction, for example as a component of a refrigerant.

Meanwhile, the methane from the scrub column is subsequently liquefied to provide LNG. Pressure reduction and separation such as 'end flash' after liquefaction can provide a gaseous methane recycle stream.

U.S. Pat. No. 4,541,852 describes a system for liquefying and subcooling natural gas in which compression power is redistributed from the closed cycle refrigerant by subcooling the LNG and reducing the pressure and flashing the LNG to recover a gaseous phase natural gas. The gaseous phase natural gas is then recompressed and recycled to the feed of the system.

The system of U.S. Pat. No. 4,541,852 requires the recompression of the gaseous phase natural gas from the depressurisation and flashing of the LNG to the feed stream pressure of 815 psia. A high power recompressor driver is therefore required.

The system of U.S. Pat. No. 4,541,852 does not include an NGL extraction system. Thus, it is not possible to alter the specification of the LNG product by removing NGLs from the feed stream. Any hydrocarbon components in the feed stream which may solidify during liquefaction may cause plugging in the system.

In a first aspect, the present invention provides a method of liquefying a hydrocarbon stream, the method at least comprising the steps of:

(a) providing a hydrocarbon feed stream;

(b) passing the hydrocarbon feed stream through an NGL recovery system to separate the hydrocarbon feed stream into at least a methane-enriched overhead stream and a C_2+ enriched bottom stream;

(c) passing the methane-enriched overhead stream through at least a first compressor to provide a methane-compressed stream;

(d) liquefying the methane-compressed stream to provide a first liquefied stream;

(e) reducing the pressure of the first liquefied stream to provide a mixed-phase stream;

(f) passing the mixed-phase stream through an end gas/liquid separator to provide an end gaseous stream and a liquefied hydrocarbon product stream;

(g) passing the end gaseous stream through one or more end-compressors to provide an end-compressed stream; and

(h) feeding at least a recycle fraction of the end-compressed stream into the methane-enriched overhead stream.

In a second aspect, the present invention provides a method of controlling the liquefaction of a hydrocarbon feed stream comprising at least the steps of:

(i) liquefying the hydrocarbon feed stream according to a method at least comprising the steps of:

(a) providing a hydrocarbon feed stream;

(b) passing the hydrocarbon feed stream through an NGL recovery system to separate the hydrocarbon feed stream into at least a methane-enriched overhead stream and a C_2+ enriched bottom stream;

(c) passing the methane-enriched overhead stream through at least a first compressor to provide a methane-compressed stream;

(d) liquefying the methane-compressed stream to provide a first liquefied stream;

(e) reducing the pressure of the first liquefied stream to provide a mixed-phase stream;

(f) passing the mixed-phase stream through an end gas/liquid separator to provide an end gaseous stream and a liquefied hydrocarbon product stream;

(g) passing the end gaseous stream through one or more end-compressors to provide an end-compressed stream; and

(h) feeding at least a recycle fraction of the end-compressed stream into the methane-enriched overhead stream;

(ii) adjusting the temperature (T_x) of the first liquefied stream to change the amount of the end gaseous stream from the end gas/liquid separator; and

(iii) controlling the amount of the recycle fraction of the end-compressed stream being fed into the methane-enriched overhead stream.

In a third aspect, there is provided a method of maximizing the production of a liquefied hydrocarbon stream comprising at least the steps of:

(a) providing a liquefaction system comprising at least a main refrigerant circuit and a first refrigerant circuit, the main refrigerant circuit comprising at least one or more main refrigerant compressors, and the first refrigerant circuit comprising one or more first refrigerant compressors;

(b) controlling the liquefaction of a hydrocarbon feed stream by controlling the amount of the recycle fraction of the end-compressed stream being combined with the methane-enriched overhead stream;

(c) driving each of the one or more main refrigerant compressors and the first refrigerant compressors at their maximum load.

In a fourth aspect, there is provided an apparatus for liquefying a hydrocarbon stream, at least comprising:

(a) an NGL recovery system to extract a C_2+ stream from a hydrocarbon feed stream to provide at least a methane-enriched overhead stream and a C_2+ enriched bottom stream;

(b) at least a first compressor to provide a methane-compressed stream from the methane-enriched overhead stream;

(c) a main cooling stage to liquefy the methane-compressed stream to provide a first liquefied stream;

(d) a pressure reducing device to reduce the pressure of the first liquefied stream to provide a mixed-phase stream;

(e) an end gas/liquid separator to separate the mixed-phase stream into an end gaseous stream and a liquefied hydrocarbon product stream;

(f) one or more end-compressors to compress the end gaseous stream to provide an end-compressed stream; and

(g) a recycle fraction line connecting the end-compressed stream with the methane-enriched overhead stream to feed at least a recycle fraction of the end-compressed overhead stream into the methane-enriched overhead stream.

Embodiments and examples of the present invention will now be described by way of example only and with reference to the accompanying non-limited drawings in which:

FIG. **1** is a diagrammatic scheme of a method of liquefying a hydrocarbon stream according to one embodiment;

FIG. **2** is a diagrammatic scheme of a method of liquefying a hydrocarbon stream according to a second embodiment; and

FIG. **3** is a diagrammatic scheme of a method of liquefying a hydrocarbon stream according to a third embodiment.

For the purpose of this description, a single reference number will be assigned to a line as well as a stream carried in that line.

In one embodiment is provided a method for liquefying a hydrocarbon stream using NGL recovery to improve the separation of C_2+ hydrocarbons from the hydrocarbon stream, and also to provide a more efficient location for the recycle of end-compressed stream back into the liquefaction process.

Referring to the drawings, FIG. **1** shows a method of liquefying a hydrocarbon stream according to one embodiment.

The hydrocarbon stream may be any suitable hydrocarbon stream such as, but not limited to, a hydrocarbon-containing gas stream able to be cooled. One example is a natural gas stream obtained from a natural gas or petroleum reservoir. As an alternative the natural gas stream may also be obtained from another source, also including a synthetic source such as a Fischer-Tropsch process.

Usually such a hydrocarbon stream is comprised substantially of methane. Preferably such a hydrocarbon stream comprises at least 50 mol % methane, more preferably at least 80 mol % methane.

Although the method disclosed herein is applicable to various hydrocarbon streams, it is particularly suitable for natural gas streams to be liquefied. As the skilled person readily understands how to liquefy a hydrocarbon stream, this is not discussed herein in detail.

Depending on the source, the hydrocarbon stream may contain one or more non-hydrocarbons such as H_2O, N_2, CO_2, Hg, H_2S and other sulfur compounds.

If desired, the hydrocarbon stream may be pre-treated before use, either as part of a hydrocarbon cooling process, or separately. This pre-treatment may comprise reduction and/or removal of non-hydrocarbons such as CO_2 and H_2S or other steps such as early cooling and pre-pressurizing. As these steps are well known to the person skilled in the art, their mechanisms are not further discussed here.

Thus, the term "hydrocarbon stream" as used herein also includes a composition prior to any treatment, such treatment including cleaning, dehydration and/or scrubbing, as well as any composition having been partly, substantially or wholly treated for the reduction and/or removal of one or more compounds or substances, including but not limited to sulfur, sulfur compounds, carbon dioxide and water.

Preferably, a hydrocarbon stream to be used herein undergoes at least the minimum pre-treatment required to subsequently allow liquefaction of the hydrocarbon stream. Such a requirement for liquefying natural gas is known in the art.

A hydrocarbon stream commonly also contains varying amounts of hydrocarbons heavier than methane such as ethane, propane, butanes and pentanes, as well as some aromatic hydrocarbons. The composition varies depending upon the type and location of the hydrocarbon stream. Hydrocarbons heavier than methane generally need to be removed from natural gas to be liquefied for several reasons, such as having different freezing or liquefaction temperatures that may cause them to block parts of a methane liquefaction plant. C_{2-4} hydrocarbons can be used as a source of natural gas liquids (NGLs) and/or refrigerant.

Scrub columns operating at the high pressures used in the liquefaction process, which is conventionally carried out at 40 to 70 bar pressure, can be used to remove C_5+ hydrocarbons from the hydrocarbon stream, for example to provide a scrubbed stream with less than 0.1 mol % C_5+ hydrocarbons.

However, high pressure separation of methane and NGLs such as in a scrub column is not as efficient as carrying the separation process out at a lower pressure, but maintaining the high pressure has conventionally been favoured in order to avoid the CAPEX and OPEX required to expand and then recompress the main hydrocarbon stream.

Consequently, in some circumstances, a scrub column may not provide the desired LNG specification. For example, the LNG specification required for the United States of America should comprise no more than 1.35 mol % C_4+, no more than 3.25 mol % propane and no more than 9.2 mol % ethane. One way of providing such a specification is to carry out the separation of NGLs at a lower pressure, for example in the range of 15 to 45 bar, more preferably 20 to 35 bar. For example, separation of C_3+ hydrocarbons from the hydrocarbon stream is preferably carried out in a pressure range of 30 to 35 bar, more preferably 33 bar, while the separation of C_2+ hydrocarbons is preferably carried out in a lower pressure range of 20 to 25 bar, more preferably 23 bar. After NGL extraction at these pressures, the hydrocarbon stream must then be further compressed prior to liquefaction. FIG. **1** shows a method of liquefying a hydrocarbon stream according to one embodiment disclosed herein, wherein a hydrocarbon feed stream **10** is passed into an NGL recovery system **12**.

The hydrocarbon feed stream **10** is provided from a hydrocarbon stream as defined above, and may undergo one or more further processes or treatments prior to the NGL recovery system **12**. For example, the hydrocarbon feed stream **10** may be cooled by one or more heat exchangers as discussed hereafter.

The hydrocarbon feed stream **10** may be provided as a low pressure mixed-phase feed stream ready for passing into an NGL recovery column **14** (shown in FIG. **2**) as part of the NGL recovery system **12**.

Alternatively and/or additionally, the NGL recovery system **12** may include at least a first expander **15** (shown in FIG. **2**) able to expand the hydrocarbon feed stream **10** to provide a mixed-phase feed stream **16** for the NGL recovery column **14**.

The NGL recovery system **12** provides a methane-enriched overhead stream **20** and a C_2+ enriched bottom stream **30** in a manner known in the art. By operating at a low pressure, for example ≦35 bar, the NGL recovery column **14** of the NGL recovery system **12** provides a more efficient separation of methane and C_2+ hydrocarbons than a conventional scrub column.

The C_2+ enriched bottom stream can pass to one or more separators such as one or more distillation columns or a fractionation column, to provide individual hydrocarbon streams such as an ethane stream, a propane stream and a butanes stream, or a combination of same, either for separate use, or for at least partial use as one or more of the components of one or more of the refrigerants of the method of liquefying a hydrocarbon stream disclosed herein.

The methane-enriched overhead stream **20** may still comprise a minor (<10 mol %) amount of C_2+ hydrocarbons, and is preferably >80 mol %, more preferably >90 mol %, methane and nitrogen.

The methane-enriched overhead stream **20** is passed through a first compressor **24** to provide a methane-compressed stream **40**. The first compressor **24** may comprise one or more compressors, stages and/or sections in a manner known in the art, and is intended to provide a methane-compressed stream **40** having a pressure in the range of 30 to 80 bar.

The methane-compressed stream **40** is then liquefied to provide a first liquefied stream **50**. Liquefaction of the methane-compressed stream **40** can be carried out by one or more cooling stages comprising one or more heat exchangers. FIG. **1** shows by way of example a 'main' cooling stage **42** able to cool the methane-compressed stream **40** to a temperature of at least −100° C.

The pressure of the first liquefied stream **50** is then reduced to provide a mixed-phase stream **60**. Reduction in the pressure of a liquefied stream may be carried out by any suitable apparatus, unit or device known in the art, such as an expansion device, including one or more valves and/or one or more expanders. FIG. **1** shows the example of using a valve **52**.

The mixed-phase stream **60** is then passed into an end gas/liquid separator **62**, such as an end-flash vessel known in the art, wherein there is provided a liquefied hydrocarbon product stream **80**, and an end gaseous stream **70**, such as an end-flash gas. The liquefied hydrocarbon product stream **80** can then be passed by one or more pumps (not shown) to storage and/or transportation facilities. Where the hydrocarbon feed stream **10** is natural gas, the liquefied hydrocarbon product stream **80** is LNG.

The end gaseous stream **70**, such as end-flash gas, from the end gas/liquid separator **62** then passes through one or more end-compressors **72** to provide an end-compressed stream **90**. The end-compressor(s) **72** may be any suitable compressor(s) having one or more stages and/or sections known in the art, and is intended to provide an end-compressed stream **90** having a pressure of >20 bar.

The end-compressed stream **90** is divided by a stream splitter **91** known in the art, to provide a recycle fraction **90***b* and a fuel-gas fraction **90***a*. The end-compressed stream **90** may also be used for one or more other purposes such as one or more heat exchangers, and may provide one or more other fractions for use other than recycle and a fuel stream. Other uses for an end-compressed stream **90** are known in the art.

The division of the end-compressed stream **90** by the stream splitter **91** may be anywhere in the range 0-100%, based on the requirements for the recycle fraction **90***b* as discussed below.

The recycle fraction **90***b* is conveniently at the same or similar pressure to the methane-enriched overhead stream **20** such that it can be readily fed into the methane-enriched overhead stream **20** by a combiner **21** upstream of the first compressor **24**.

FIG. **2** shows a method of liquefying a hydrocarbon stream according to a second embodiment disclosed herein.

In FIG. **2**, a hydrocarbon feed stream **10** is passed through a first heat exchanger **110**, a second heat exchanger **112**, preferably being a low pressure kettle heat exchanger, and a third heat exchanger **114**, prior to passing into the NGL recovery system **12**. In this way, the temperature of the hydrocarbon feed stream **10** can be lowered to below 0° C.

In FIG. **2**, the NGL recovery system **12** comprises a pre-NGL separator **17**, able to provide a bottom liquid stream **18** which passes through a valve **13** and into the NGL recovery column **14**, and an overhead gaseous stream **19** which passes into the NGL expander **15** to provide a mixed-phase feed stream **16** which passes into the NGL recovery column **14** at a height above the bottom liquid stream **18**.

The NGL recovery column **14** provides a C_2+ enriched bottom stream **30**, and an overhead stream **31** which passes through the first and third heat exchangers **110**, **114** to provide some cooling to the hydrocarbon feed stream **10**. Thereafter, the overhead stream **31** can pass through a turbo-compressor **32** which is preferably mechanically interlinked and driven directly by the NGL expander **15** so as to capture work energy created by the NGL expander **15** in a manner known in the art. The turbo-compressor provides the methane-enriched overhead stream **20** that is provided from the NGL recovery system **12**.

As described above, the methane-enriched overhead stream **20** can be combined by a combiner **21** with a recycle fraction **90***b* of the end-compressed stream **90**, to provide a feed stream into the one or more first compressors **24**. Optionally, an intercooler **25** may be provided with one or more first compressors **24**. The provided methane-compressed stream **40** may be cooled by a first cooler **26**. The intercooler **25** and first cooler **26** may be water and/or air coolers known in the art. The methane-compressed stream **40** can pass through a fourth heat exchanger or heat exchanger system **116**, preferably being a high pressure kettle heat exchanger **116***a*, a medium pressure heat exchanger **116***b* and a low pressure heat exchanger **116***c*, to provide a cooled methane-compressed stream **40***a* prior to entering the main cooling stage **42**.

According to one embodiment disclosed herein, there is provided a first refrigerant circuit **100** comprising a first refrigerant compressor **101** (being one or more compressors), driven by a first refrigerant compressor driver D**2**, which provides a compressed refrigerant stream **108**. Compressed refrigerant stream **108** is passed through one or more coolers **102** and a valve **103** to provide a cooled expanded refrigerant stream **104** into one or more heat exchangers. By way of example only, FIG. **2** shows the first refrigerant circuit **100** having a division of the refrigerant supply to two parallel first high pressure (HP) kettle heat exchangers **105***a*, **105***b*. Each first high pressure heat exchanger **105***a*, **105***b* then passes refrigerant via an expansion device (not shown) to medium pressure (MP) kettle heat exchangers **106***a*, **106***b*. The refrigerant from medium pressure kettle heat exchanger **106***a* is supplied to a low pressure (LP) kettle heat exchanger **107***a*. In the embodiment shown in FIG. **2**, the refrigerant from medium pressure (MP) kettle heat exchanger **106***b* is divided to supply two low pressure heat exchangers **107***b*, **107***c*. Optionally, low pressure heat exchanger **107***c* can correspond to the second heat exchanger **112** to cool the hydrocarbon feed stream **10**. The refrigerant from the low pressure kettle heat exchangers **107***a*, **107***b*, **112** is then re-compressed by the first refrigerant compressor **101**.

Further optionally, the HP heat exchangers **105***a*,**105***b*, can correspond to the fourth HP heat exchanger **116***a* able to provide cooling to the methane-compressed stream **40** after the first compressor **24**. Similarly, the MP heat exchangers **106***a*, **106***b* can correspond to the fourth MP heat exchanger **116***b* and the LP heat exchangers **107***a*, **107***b* can correspond to fourth LP heat exchanger **116***c*.

The provision of a first refrigerant circuit in a process for liquefying a hydrocarbon stream is known in the art, and is sometimes termed a 'pre-cooling refrigerant circuit'. A first refrigerant circuit may also provide some cooling to one or more other streams, including refrigerant in one or more other refrigerant circuits in the hydrocarbon liquefaction process, such as the main refrigerant in a main refrigerant circuit.

The present disclosure is not limited by the provision of the first refrigerant circuit **100**, or by the location of each heat exchanger in the first refrigerant circuit **100**.

The first refrigerant of the first refrigerant circuit may be a single component refrigerant such as propane or propylene, preferably propane, or a refrigerant comprising one or more components selected from the group comprising nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

Optionally, the first refrigerant compressor driver D2 of the first refrigerant compressor **101** may also drive the first compressor **24**, such that the first compressor **24** is mechanically interlinked and commonly driven with at least one refrigerant compressor, typically by use of a common drive shaft **27**.

The cooled methane-compressed stream **40***a* from the fourth heat exchanger system **116** passes into the main cooling stage **42**. The fourth heat exchanger system may comprise one of more fourth high pressure kettle heat exchangers **116***a*, one or more fourth medium pressure heat exchangers **116***b* and one or more fourth low pressure heat exchangers **116***c*. Only a single fourth HP, MP and LP kettle heat exchanger **116***a*, **116***b*, **116***c* respectively is shown in FIG. **2**.

The main cooling stage **42** may comprise one or more heat exchangers and one or more refrigerant circuits, either being in series, parallel or both. FIG. **2** shows the main cooling stage **42** having a main cryogenic heat exchanger (MCHE) **54** such as a spool wound heat exchanger, able to cool and at least partly liquefy the cooled methane-compressed stream **40***a* to provide the first liquid stream **50**.

FIG. **2** also shows the main cooling stage **42** having a main refrigerant circuit **44** which may use any refrigerant, preferably a mixed refrigerant comprising two or more of the group comprising: nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

The main refrigerant circuit **44** may involve any number of refrigerant compressors, coolers and separators to provide one or more refrigerant streams to the MCHE **54** in a manner known in the art.

By way of example only, FIG. **2** shows the main refrigerant circuit **44** having first and second main refrigerant compressors **45***a*, **45***b*, which are commonly driven by a main refrigerant compressor driver D3, to provide a pressurised refrigerant stream **46** which passes through one or more coolers **47**, such as one or more water and/or air coolers, followed by a fifth heat exchanger system **118**, comprising one or more fifth HP kettle heat exchangers **118***a*, one or more fifth MP kettle heat exchangers **118***b* and one or more fifth LP kettle heat exchangers **118***c*. Only a single fifth HP, MP and LP kettle heat exchanger **118***a*, **118***b*, **118***c* is shown in FIG. **2**. The fifth HP, MP and LP heat exchangers **118***a*, **118***b*, **118***c* may correspond to one or more of the first HP, MP and LP heat exchangers **105***a*, **105***b*, **106***a*, **106***b*, **107***a*, **107***b*, **107***c* in the first refrigerant circuit **100**. A cooled pressurised refrigerant stream **48** is thus provided which is passed to a refrigerant separator **55**. The refrigerant separator **55** is adapted to provide a light refrigerant stream **56** and a heavy refrigerant stream **57** in a manner known in the art, which refrigerant streams **56**, **57** pass through the MCHE **54** for further cooling, are expanded by one or more valves and/or expanders **58***a*, **58***b*, before re-entering the MCHE **54** to provide cooling therein. The MCHE **54** provides a warmed refrigerant stream **59** for recompression in first and second main refrigerant compressors **45***a*, **45***b*. Second main refrigerant compressor **45***b* may be fitted with one or more intercoolers **43**, such as one or more water and/or air coolers.

As described above, the first liquefied stream **50** from the MCHE **54** passes through a pressure reducing device, such as valve **52** into an end gas-liquid separator **62** such as an end-flash vessel, to provide an end gaseous stream **70** such as end-flash gas, and a liquefied hydrocarbon product stream **80**. Alternatively the pressure reducing device may be an expander or a combination of valve and expander. The end gaseous stream **70** passes through one or more end-compressors **72** shown in FIG. **2** to be driven by an end compressor driver D**4**, to provide an end-compressed stream **90**. A recycle fraction **90***b* of the end-compressed stream **90** is provided by a divider **91** to be fed into the methane-enriched stream **20**.

FIG. **3** shows an alternative layout for a method of liquefying a hydrocarbon stream according to a third embodiment. FIG. **3** uses the same arrangement as the embodiments shown in FIG. **2**, with a different layout for the cooling provided by the first refrigerant circuit **100**.

FIG. **3** shows a hydrocarbon feed stream **10** passing through a NGL recovery system **12** to provide a methane-enriched overhead stream **20**, which passes through at least a first compressor **24** to provide a methane-compressed stream **40**. FIG. **3** shows the first refrigerant circuit **100** comprising a first refrigerant compressor **101** driven by the first refrigerant compressor driver D2, and one or more coolers **102** and valves **103** thereafter.

FIG. **3** shows a heat exchange system **120** as a schematic representation of the provision of cooling by the first refrigerant circuit **100** to other streams in the method of liquefaction. The broken squares **122** of the heat exchange system **120** represent one or more actual heat exchangers, such as kettles, through which the first refrigerant of the first refrigerant circuit **100** can pass to provide cooling to the other streams shown passing through the heat exchange system **120**.

The first refrigerant circuit **100** provides cooling to the methane-compressed stream **40** to provide a cooled methane-compressed stream **40***a* in the manner of the fourth heat exchanger **116** in FIG. **2**, and cooling to the main refrigerant of the main refrigerant circuit **44** (after its passage through the one or more main compressors **45** driven by main refrigerant compressor driver D3, and one or more coolers **47** to provide a cooled pressurised refrigerant stream **48**) in the manner of the fifth heat exchanger **118** shown in FIG. **2**. Cooling of the cooled pressurised refrigerant stream **48** in heat exchange system **120** provides a further cooled pressurised refrigerant stream **49**, which is passed to a valve **41** and then to main cooling stage **42**.

Line **124** represents a further stream which can be cooled by the heat exchange system **120**, to provide a cooled further stream **124***a*. Such cooling could be provided for example to the hydrocarbon feed stream **10** through lines **126** and **126***a* in a manner related to the second heat exchanger **112** shown in FIG. **2**.

FIG. **3** shows that after passage of the cooled methane-compressed stream **40***a* through the main cooling stage **42**, there is provided the first liquefied stream **50** having a temperature T_x.

The embodiments disclosed herein provide an advantageous method of liquefying a hydrocarbon stream wherein the pressure of an end-compressed stream **90** is the same or similar to the pressure of the methane-enriched overhead stream **20** following NGL recovery, such that direct recycle of at least a fraction of the end-compressed stream **90** is possible back into the liquefaction process.

The embodiments disclosed herein also provide a method of controlling the liquefaction of the hydrocarbon feed stream **10** comprising:

(i) liquefying the hydrocarbon feed stream **10** as described above;

(ii) adjusting the temperature T_x of the first liquefied stream **50** shown in FIG. **3** to change the amount of the end gaseous stream **70** from the end gas/liquid separator **62**; and

(iii) controlling the amount of the recycle fraction **90***b* of the end-compressed stream **90** being fed into the methane-enriched stream **20**.

Adjusting the temperature T_x of the first liquefied stream **50** allows the advantageous adjusting and/or shifting of the power requirements for one or more of the drivers of the compressors used in the liquefaction process.

For example, raising the temperature T_x of the first liquefied stream **50** by a few degrees centigrade, such as to −140° C. or −130° C., increases the provision of the end gaseous stream **70** in the end gas/liquid separator **62**, such that more power is required from the end-compressor driver D**4** to compress the increased end gaseous stream **70**, and more power is consequentially required by the first compressor driver D**1** and the first refrigerant compressor driver D**2** for the same recycle fraction **90***b* volume. However, less power is required from the main refrigerant compressor driver D**3** (as the liquefaction temperature in the main cooling stage **42** is higher).

Conversely, decreasing the temperature T_x reduces the provision of end gaseous stream **70**, reducing the compressor drivers D**4**, D**1** and D**2** power loads (for the same recycle fraction **90***b* volume), but increasing the main refrigerant compressor driver D**3** power load (so as to lower the liquefaction temperature).

The power loads of the compressor drivers D**1**-**4** shown in FIGS. **2** and **3** can be further varied by controlling the amount of the recycle fraction **90***b* and fuel fraction **90***a*. There may be variation in the demand of the fuel fraction **90***a* by its one or more users, which determines the amount of the recycle fraction **90***b*.

FIG. **3** shows an interrelationship between the four compressor drivers D**1**-**4** and the end stream splitter **91** that allows understanding of the variation therebetween.

In this way, the method of controlling the liquefaction of a hydrocarbon feed stream **10** provided herein allows the user to control the liquefaction process by shifting the power load between the compressor drivers for a given hydrocarbon feed stream flow.

For example, where one or more of the compressor drivers is constrained, i.e. already fully loaded and unable to provide any further compression of the stream therethrough, variation of one or more other of the other compressor drivers is possible to accommodate and if necessary relieve the constrained driver, by variation of the temperature T_x of the final liquefied stream **50** and controlling the amount of the recycle fraction **90***b*. Typically, it is the first refrigerant compressor driver D**2** or the main refrigerant compressor driver D**3** which are constrained, being the bigger drivers in a liquefaction process.

The embodiments disclosed herein also provide a method of maximizing the production of the liquefied hydrocarbon stream **80** comprising at least the steps of:

(a) controlling the liquefaction of the hydrocarbon feed stream **10** as described above, comprising the main refrigerant circuit **44**, the one or more main refrigerant compressors **45**, the first refrigerant circuit **100** and the one or more first refrigerant compressors **101**; and

(b) driving each of the one or more main refrigerant compressors **45** and the first refrigerant compressors **101** at their maximum load.

In this way, it is possible to increase the liquefied hydrocarbon stream production by fully loading all the refrigerant drivers D**1**-**4** where one or more of said drivers may not be otherwise required to be fully loaded.

For example, one or more of the drivers D**1**-**4**, especially the first refrigerant compressor driver D**2** and the main refrigerant compressor driver D**3**, may have spare capacity, whilst still being able to provide, in relation to the other compressor drivers, the expected or 'normal' amount of liquefied hydrocarbon product.

The liquefied hydrocarbon stream may be a liquefied natural gas stream.

In the presently disclosed embodiments, control of the temperature T_x of the first liquefied stream **50**, and of the amount of the recycle fraction **90***b* of the end-compressed stream **90** allows maximization of at least the first refrigerant compressor driver D**2** and the main refrigerant compressor driver D**3** at full power, so as to provide an increase in the liquefied hydrocarbon product stream **80**.

Table 1 below provides the power duties and other data for the drivers and certain streams at various parts of an example of the process disclosed herein such as that shown in FIGS. **2** and **3** herewith, in comparison with a process involving no recycle of the end-compressed stream, i.e. having no recycle fraction **90***b*.

TABLE 1

Stream/Driver	Unit	Without Recycle	With Recycle
D1	MW	17.52	30.09
D2	MW	89.20	90.19
D3	MW	178.40	180.29
D4	MW	68.79	77.75
80	MTPA	7.50	8.00
70	kg/s	23.03	41.11
90b	kg/s	0.00	18.92
Pressure of first compressor 24	Bar	25.15	25.15
Temperature T_x	° C.	−149.9	−144.5

Table 1 confirms that with similar power provided by the first refrigerant compressor driver D**2** and the main refrigerant compressor driver D**3**, an increase of nearly 7% stream **80** (e.g. LNG) production can be provided by using a recycle fraction of the end-gaseous stream **90***b*, and by fully using the power available in the other compressor drivers D**1** and D**4**.

Table 1 shows an example and comparative example (i.e. a process with and without recycle) in which the first refrigerant compressor driver D**2** and the main refrigerant driver D**3** operate at a full loading corresponding to their installed power outputs. In the comparative Example without recycle, the first compressor driver D**1** and the end-compressor driver

D4 operate at a level of consumed power significantly lower than their corresponding installed power. It is only in the example with recycle that drivers D1 and D4 can operate at a level of consumed power approaching their installed power.

The person skilled in the art will understand that the present invention can be carried out in many various ways without departing from the scope of the appended claims.

The invention claimed is:

1. A method of liquefying a hydrocarbon stream, the method at least comprising the steps of:

(a) providing a hydrocarbon feed stream;

(b) passing the hydrocarbon feed stream through an NGL recovery system to separate the hydrocarbon feed stream into at least a methane-enriched overhead stream and a C_2+ enriched bottom stream;

(c) passing the entire methane-enriched overhead stream through at least a first compressor to provide a methane-compressed stream;

(d) liquefying the methane-compressed stream to provide a first liquefied stream;

(e) reducing the pressure of the first liquefied stream to provide a mixed-phase stream;

(f) passing the mixed-phase stream through an end gas/liquid separator to provide an end gaseous stream and a liquefied hydrocarbon product stream;

(g) passing the end gaseous stream through one or more end-compressors to provide an end-compressed stream; and

(h) feeding at least a recycle fraction of the end-compressed stream into the methane enriched overhead stream.

2. The method as claimed in claim **1**, wherein the NGL recovery system comprises an expander.

3. The method as claimed in claim **2**, wherein the NGL recovery system further comprises one or more turbo-compressors mechanically interlinked with the expander to be driven by the expander.

4. The method as claimed in claim **3**, wherein the NGL recovery system further comprises an NGL recovery column, and wherein at least a fraction of the hydrocarbon feed stream passes into the expander to provide a mixed-phase feed stream which passes into the NGL recovery column, which produces an overhead stream which passes through the turbo-compressor to produce the methane-enriched overhead stream.

5. The method as claimed in claim **1**, comprising liquefying the methane-compressed stream in at least a main cooling stage comprising one or more main refrigerant circuits.

6. The method as claimed in claim **5**, wherein at least one of the main refrigerant circuits comprises a mixed refrigerant comprising two or more of the group consisting of nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

7. The method as claimed in claim **5**, wherein at least one of the group consisting of the hydrocarbon feed stream and the methane compressed stream is cooled by one or more first refrigerant circuits comprising one or more first refrigerant circuit compressors before said liquefying in the main cooling stage.

8. The method as claimed in claim **7**, wherein the first refrigerant circuit comprises at least one heat exchanger for cooling the hydrocarbon feed stream and at least one heat exchanger for cooling the methane-compressed stream.

9. The method as claimed in claim **7**, wherein the refrigerant of the first refrigerant circuit essentially consists of one or more of the group consisting of nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

10. The method as claimed in claim **1**, wherein the pressure of the methane-enriched overhead stream and the pressure of the recycle fraction of the end-compressed stream are in the range of 15 to 45 bar.

11. The method as claimed in claim **1**, wherein the first compressor is commonly driven together with at least one refrigerant compressor, by a first refrigerant compressor driver.

12. The method as claimed in claim **11**, wherein the refrigerant compressor is part of a first refrigerant circuit or a main refrigerant circuit.

13. The method as claimed in claim **1**, wherein the hydrocarbon feed stream is a natural gas stream and the liquefied hydrocarbon product stream is a liquefied natural gas stream.

14. A method of controlling the liquefaction of a hydrocarbon feed stream comprising at least the steps of:

(i) liquefying the hydrocarbon feed stream according to a method at least comprising the steps of:

(a) providing a hydrocarbon feed stream;

(b) passing the hydrocarbon feed stream through an NGL recovery system to separate the hydrocarbon feed stream into at least a methane-enriched overhead stream and a C_2+ enriched bottom stream;

(c) passing the entire methane-enriched overhead stream through at least a first compressor to provide a methane-compressed stream;

(d) liquefying the methane-compressed stream to provide a first liquefied stream;

(e) reducing the pressure of the first liquefied stream to provide a mixed-phase stream;

(f) passing the mixed-phase stream through an end gas/liquid separator to provide an end gaseous stream and a liquefied hydrocarbon product stream;

(g) passing the end gaseous stream through one or more end-compressors to provide an end-compressed stream; and

(h) feeding at least a recycle fraction of the end-compressed stream into the methane-enriched overhead stream;

(ii) adjusting the temperature (Tx) of the first liquefied stream to change the amount of the end gaseous stream from the end gas/liquid separator; and

(iii) controlling the amount of the recycle fraction of the end-compressed stream being fed into the methane-enriched overhead stream.

15. A method of maximizing the production of a liquefied hydrocarbon stream, comprising at least the steps of:

(a) providing a liquefaction system comprising at least an NGL recovery system, a main refrigerant circuit and a first refrigerant circuit and an end gas/liquid separator to separate an end gaseous stream from a mixed-phase stream and an end compressor to provide an end-compressed stream, the main refrigerant circuit comprising at least one or more main refrigerant compressors, and the first refrigerant circuit comprising one or more first refrigerant compressors;

(b) passing a hydrocarbon feed stream through the NGL recovery system to produce a methane-enriched overhead stream from the hydrocarbon feed stream;

(c) controlling the liquefaction of the methane-enriched overhead stream in the liquefaction system, by adjusting the temperature (Tx) of a first liquefied stream to change the amount of the end gaseous stream from the end gas/liquid separator;

(c1) passing the end gaseous stream through the end compressor to provide the end-compressed stream;

(d0) providing a recycle fraction from the end-compressed stream by a divider and feeding the recycle fraction into the methane enriched overhead stream; and

(d) controlling the fraction of the end-compressed stream provided as the recycle fraction;

(e) driving each of the one or more main refrigerant compressors and the one or more first refrigerant compressors at their maximum load.

16. The method as claimed in claim **15**, wherein the liquefied hydrocarbon stream is a liquefied natural gas stream.

17. Apparatus for liquefying a hydrocarbon stream, the apparatus at least comprising:

(a) an NGL recovery system to extract a C_2+ stream from a hydrocarbon feed stream to provide at least a methane-enriched overhead stream and a C_2+ enriched bottom stream;

(b) at least a first compressor arranged to receive the entire methane-enriched overhead stream to provide a methane-compressed stream from the methane-enriched overhead stream;

(c) a main cooling stage to liquefy the methane-compressed stream to provide a first liquefied stream;

(d) a pressure reducing device to reduce the pressure of the first liquefied stream to provide a mixed-phase stream;

(e) an end gas/liquid separator to separate the mixed-phase stream into an end gaseous stream and a liquefied hydrocarbon product stream;

(f) one or more end-compressors to compress the end gaseous stream to provide an end-compressed stream; and

(g) a recycle fraction line connecting the end-compressed stream with the methane-enriched overhead stream to feed at least a recycle fraction of the end-compressed overhead stream into the methane-enriched overhead stream.

18. The apparatus as claimed in claim **17**, wherein said at least first compressor is provided between the NGL recovery system and the main cooling stage such that the methane-enriched overhead stream as obtained from the NGL recovery system is passed through said at least first compressor prior to passing into the main cooling stage.

19. The method as claimed in claim **1**, wherein said methane-enriched overhead stream as obtained from the NGL recovery system is passed through said at least first compressor prior to said liquefying to provide said methane-compressed stream.

20. The method as claimed in claim **14**, wherein said methane-enriched overhead stream as obtained from the NGL recovery system is passed through said at least first compressor prior to said liquefying to provide said methane-compressed stream.

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